Joint Inversion of Ground-Penetrating Radar and Hydrological Measurements

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RESEARCH OBJECTIVES

Ground-penetrating radar (GPR) measurements are not directly related to soil hydraulic parameters (e.g., permeability and the parameters of the capillary pressure and relative permeability functions). However, GPR measurements are highly sensitive to fluid distribution (and to transients therein) and are thus potentially useful for inferring soil hydraulic parameters in the vadose zone, especially when combined with additional data types. The objective of this study is to develop a method that jointly uses cross-borehole GPR measurements and hydrological measurements to provide quantitative estimates of field-scale soil hydraulic parameters.
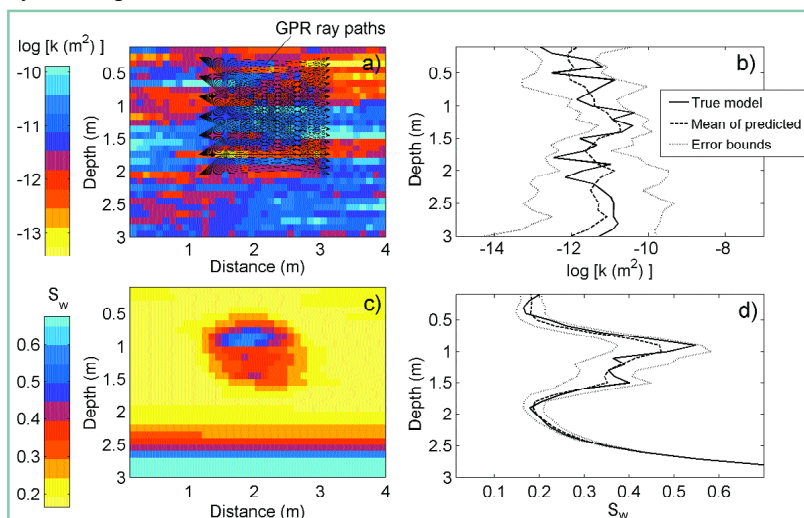

Figure 1. A heterogeneous permeability model (a) is used to simulate a water injection experiment. Joint inversion of synthetic GPR and neutron probe data allow for accurate estimates of permeability (b), which can be used to predict flow phenomena, such as the water saturation profile at a given time (c–d). Vertical cross sections through the two-dimensional models of (a) and (c) are shown in (b) and (d), respectively.

APPROACH

How a hydrological system responds to external stimuli, such as the injection of water, is influenced by the soil hydraulic parameters and their variations in space. Corresponding GPR measurements of the same system also depend on the soil hydraulic functions—although indirectly—since the soil hydraulic functions influence the water distribution, which in turn influences the GPR measurements. Our approach allows for the estimation of soil hydraulic parameters through the coupled simulation (and inversion) of multiple-offset cross-borehole GPR travel times and hydrological measurements collected during transient flow experiments. Joint inversion proceeds by perturbing the unknown hydraulic parameters—which alters the simulated water distributions and subsequent geophysical observations—until a good match is achieved between the simulated and measured (geophysical and hydrological) observations.

ACCOMPLISHMENTS

Within the context of water injection experiments, we tested the approach with synthetic examples and also applied it to field data. The synthetic examples show that while realistic errors in the petrophysical function (the function that relates soil porosity and water saturation to the effective dielectric constant) cause substantial errors in the soil hydraulic parameter estimates, simultaneously estimating petrophysical parameters and soil hydraulic parameters allows for these errors to be minimized. Additionally, inaccuracy in the GPR simulator can cause systematic error (bias) in the simulated travel times, making necessary the simultaneous estimation of a correction parameter. After demonstrating the usefulness of the method with synthetic examples (Figure 1), we applied it in a three-dimensional field setting to field data (GPR and neutron probe data) collected during an infiltration experiment at the U.S. Department of Energy (DOE) Hanford site in Washington. We find that inclusion of GPR data in the inversion procedure provides hydrological models that predict water-content distributions better than models obtained using neutron probe data alone.

SIGNIFICANCE OF FINDINGS

GPR and other geophysical methods offer high resolution and minimally invasive information that has traditionally been difficult to relate to hydrological properties. Our joint inversion approach provides a way to incorporate geophysical data into hydrological investigations in a meaningful and quantitative way. The flexible framework we have developed should prove useful for inclusion of additional geophysical data types, such as from seismic and electrical methods.

RELATED PUBLICATIONS

Kowalsky, M.B., S. Finsterle, and Y. Rubin, Estimating flow parameter distributions using ground-penetrating radar and hydrological measurements during transient flow in the vadose zone. Advances in Water Resources, 27 (6), 583–599, 2004. Berkeley Lab Report LBNL-53786.

Kowalsky, M.B., S. Finsterle, J. Peterson, S. Hubbard, Y. Rubin, E. Majer, A. Ward, and G. Gee, Estimation of field-scale soil hydraulic and dielectric parameters through joint inversion of GPR and hydrological data. Water Resources Research (in press), 2005. Berkeley Lab Report LBNL-57560.

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